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ROOT DISEASE OF SUGAR CANE IN
LOUISIANA

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CONTENTS

	Page		Page
Symptoms and effects of root disease	2	Recommendations	16
Effect on plant cane	3	Adoption of tolerant varieties	16
Effect on stubble cane	8	Direct control of root parasites	18
Symptoms on stubble cane	9	Soil improvement and better	
Causes of root disease	9	methods of cultivation	18
Root-eating animals	9	Summary	19
Root-rot	13		

The frequency of crop failure and the general reduction of yields of sugar cane in Louisiana have stimulated widespread interest and study of the possible factors involved. From the divergence of opinion expressed in scientific publications and trade journals it is evident that no single condition can be held responsible, but that the frequently diminished and highly fluctuating yields are probably due to a combination of interacting causes the individual importance of which is difficult to estimate. Of these, the reduction in yield from mosaic, "root disease," red rot, and moth borer have been particularly stressed.

Root disease in Louisiana, as in most sugar-cane regions, is now a major problem because of its prevalence in soils long utilized for cane culture. For many years pathologists have recognized that the unthrifty appearance of many of the fields in Louisiana was definitely correlated with deficient root systems. In a discussion of the Louisiana situation as long ago as 1919, Brandes¹ stated that "mosaic does not by any means present the practical difficulties in the way of control measures to be met with in root rot. Root rot, in fact, is to be regarded as a far more serious problem for the Louisiana cane planter than mosaic on this account." The lack of vigor and extreme yellowing noticeable last spring in hundreds of

¹ Brandes, E. W. The mosaic disease of sugar cane and other grasses. U. S. Dept. Agr. Bul. 829, pp. 26. 1919.

fields covering the southeastern section of the sugar belt were traceable in a large measure to root suppression, as was learned by careful examination of many cases.

So-called root disease, or root rot, has been rather extensively studied in several countries for a number of years; but unfortunately nowhere has much light been shed on either its cause or control, other than by substitution of more vigorous and sometimes necessarily lower sugar-yielding varieties. Louisiana is years behind in adopting this control measure, which, aside from crop diversification and soil improvement, is thus far the only one that can be definitely recommended. However, from intensive studies to determine the cause or causes of this complex and obscure trouble now being undertaken by both the Louisiana Agricultural Experiment Station and the United States Department of Agriculture, it is hoped that a more direct and satisfactory method of control may be developed. Progress in this direction has already been made, (1) by the discovery of extensive root damage caused by snails predisposing the roots to decay, which was reported by the writer² last year, and (2) by the finding of hitherto unsuspected root-rotting fungi, more recently announced by the State pathologists.³ Although there are possibly several ill-defined root diseases affecting sugar cane in Louisiana, the most prevalent type, according to the writer's observations, is that in which the stunting, distortion, and rotting of the roots are instigated by soil-inhabiting snails and other animals.

The purpose of this circular is to outline the symptoms, effects, and predisposing conditions for this root disease (this term being tentatively used by the writer to include both animal damage and subsequent root rot), although further study may show that some of the varied manifestations of advanced cases here described are attributable to other causes. The discovery in the United States of two species of root-eating centipedes involved in the trouble is reported.

SYMPTOMS AND EFFECTS OF ROOT DISEASE

Root disease of sugar cane belongs to that class of troubles popularly attributed to the weather, lack of soil fertility, faulty cultivation, or some assumed or imaginary cause. This is natural and not without some foundation in fact, because practically all diseases, both plant and animal, are profoundly influenced by changes in environment or in the individual itself. It is essential, however, to distinguish between the direct effects of these conditions on the plant and their indirect influence on the development of disease. Thus weather fluctuations, which would not have a permanently deleterious effect on a healthy individual, might result in the actual death of a diseased one. This is particularly true with those diseases which curtail or prevent normal root growth.

Since the effect of root disease on plant cane was well illustrated in so many fields during the drought in the spring of 1925, that condition may be taken as an example in explaining the complex situation which usually exists. It will be discussed in detail, because the yellowing and dying of plants at that time, particularly in the lower

² Rands, R. D. Snails as predisposing agents of sugar-cane "root disease" in Louisiana. *In Jour. Agr. Research*, vol. 28, pp. 969-970. 1924.

³ Edgerton, C. W., Taggart, W. G., and Tims, E. C. Sugar-cane disease situation in 1923 and 1924. *La. Agr. Exp. Sta. Bul.* 191, 44 pp., illus. 1924.

coast sections, seem to have been typical of what has occurred in lesser degree many times in the past in Louisiana and doubtless contributed greatly toward reducing yields.

EFFECT ON PLANT CANE

In the Terrebonne and adjacent districts of Louisiana, where the development of the crop was carefully followed by the writer, the spring of 1925 opened with a rather prolonged dry spell. As there was plenty of moisture in the soil from the winter rains, a dry March was welcomed by the planters, who were thus enabled to get through the initial tillage operations in good time. The continued absence of rain during April unquestionably interfered with the germination and growth of such spring-planted crops as maize, potatoes, and soybeans. However, the fall-planted cane where, on account of the better settled condition of the seed bed and the loose-surface mulch, one would expect the least moisture deficiency, actually showed except on the lightest soils the worst apparent effect of the drought. Entire fields of the mixed and heavy soils turned yellow and burned, and hundreds of thousands of plants died outright. The importance of such an unfavorable turn in the crop, even to the succeeding stubble generation, is too generally realized to need elaboration here, but the factors responsible for it seem to be not so generally appreciated. Most planters naturally attributed the condition entirely to the drought, which was correct so far as the final outcome was concerned; but the fact was that long before there was any indication of drought, the roots of many of the plants were becoming so mutilated or destroyed by root disease that even under average climatic conditions only severe retardation and reduced yield could have been expected. The latter, in fact, occurred in several other parts of the sugar belt where, owing to a more equable spring, very few plants died, but, nevertheless, the deficient root systems failed to sustain growth sufficiently during subsequent dry spells to give satisfactory yields.

In order to evaluate the approximate part played by root disease in the development of the unfortunate condition of the plant cane crop in the lower coast sections, it is necessary to go back and trace the events which preceded the spring drought. The seed bed in 1924 was often rather poorly prepared, owing to the dry summer. The soil was not always thoroughly pulverized, but sufficient moisture was usually present for the germination of even the earliest planted cane. From the standpoint of growth alone, the conditions were not particularly unfavorable. The seed roots came out promptly in October and November but suffered severe injury from root-eating parasites, whose multiplication and access to the roots had been favored by the mild weather and the porous cloddy condition of the soil. Periodic examination showed that extensive root and seed rotting continued throughout the winter.

The health of the temporary or seed roots is important not only in promoting vigorous growth of the sprouts but also probably in the preservation of the seed itself during the dormant season. Often entire whorls of these emerging seed roots were found to have been eaten back flush with the surface of the stalk by the minute soil animals. This is illustrated in Figure 1, which shows one node of a seed stalk magnified five times, on which the development of practi-

cally all roots was prevented. Four young snails clung to the stalk as it was carefully lifted from the soil. The general prevalence and severity of seed-root mutilation doubtless facilitated infection of the seed by the red-rot and other fungi, which did great damage



FIG. 1.—Magnified portion of a germinating seed stalk of sugar cane, showing the destruction of emerging seed roots by snails, four specimens of which are seen. $\times 5$

in spite of the relative scarcity of borers. Although other factors were doubtless involved in the seed decay, the writer's observations during November and December, 1924, indicate that seed-root mutilation must have had an important influence.

In spite of the extensive seed decay and loss of seed roots on the mixed and heavy soils, so much seed is ordinarily planted that a fair stand was obtained even in the spring of 1925. Counts in several fields on April 13 showed an average of one plant every 21 inches. This indicates that about 15 per cent of the sound eyes planted in the fall had germinated and survived. Considering the situation underground, even that high a percentage was surprising. Compared with previous years, however, the conditions on such soils in Louisiana were, after all, but little worse than usual, since C. W. Edgerton has shown by extensive germination experiments that, as a rule, only about 20 per cent of the sound eyes planted in the fall ever develop plants.

In spite of the striping and mottling from 100 per cent primary mosaic infection, the young plants grew well, and the superficial appearance of the crop in March, 1925, was described by the planters as excellent. However, this did not continue long.

Mosaic symptoms became more pronounced, of course, as the plants grew taller, but it soon became evident that something else was radically wrong. Careful and repeated examinations showed that the few remaining healthy seed roots were not supplying sufficient moisture and that the rapidly growing young plants were being forced to put out more and more roots of their own. These likewise were being severely attacked by the root-eating and root-rotting organisms. Often all but 1 or 2 of the first 8 to 15 roots were killed at the tips or in their entirety before reaching a length of 3 inches. Many which were injured only at the growing tip began to branch farther back, so that in spite of their bunchy, short root systems the young plants up to nearly the 1st of April obtained sufficient moisture and food materials to continue growth. The mutilated condition of the roots at that time is illustrated in Figure 2. Had rain come at regular intervals and kept the surface soil moist, many of the plants would doubtless have continued to grow and would have accumulated enough vigor to at least partially evade their adversaries and become better established in the deeper layers of soil. But the dry weather continued, the soil about these short roots began to dry out, and in their already injured and weakened condition only a feeble effort was made to follow the available moisture downward. Decay of the seed stalks hastened by warmer weather cut off further assistance to the young plants from this source. Practically every plant on the mixed and heavy soils, particularly where the poorly pulverized condition prevented much capillary movement of water from below, gradually yellowed. Many of the leaves dried and burned at the tips and margins, and, as already stated, the stand was greatly reduced. The surviving plants, although keeping alive, made no growth whatever for more than a month. Even after heavy rains set in their recovery was slow and feeble, and not a few more succumbed during a further dry spell in May. Although nearly ideal weather prevailed during the remainder of the season, thin stands of late, uneven, and poorly stooled cane were the unfortunate outcome.

From the above history and analysis of conditions in the lower coast sections in the spring of 1925, it is obvious that a number of interacting factors were operating to reduce the crop prospect. The more important of these were evidently (1) drought, (2) unfavorable physical condition of the soil, (3) root disease, (4) mosaic, and (5) seed decay. In the absence of quantitative data, only an approximation of the relative importance of the root-disease factor can be

made. From the extensive observational evidence it seems reasonable to presume that had the roots been allowed to develop normally the effect of the drought and probably also to some extent the effect of the remaining factors would have been greatly minimized.

The probable correctness of this conclusion was shown by many of the fields just referred to. Even in the most severely burned areas there often occurred green, robust, vigorously growing individuals scattered through the field or in patches, with the yellowed or dying plants often as close as 2 or 3 inches on either side. The field illus-



FIG. 2.—Gnarled and mutilated root system of a young plant of the D-74 variety of sugar cane grown in heavy soil. Most of the root tips have been killed and the remaining portions much pitted by snails and centipedes

trated in Figure 3, photographed May 21, 1925, shows the unevenness of stand and condition of plants typical at that time of large areas on heavy soils. If drought had been solely responsible for the yellowing, rolling, and firing of the leaves, as many planters claimed, how did these green plants escape its effect? Comparisons of the roots told the story. The green plants, through accident, had less injury from the root parasites or greater support from the seed, or in some unknown way had succeeded in sending their roots down into the moisture-containing layers below the mother seed stalk. The yellowed and dying plants, on the other hand, had failed. Examination of hundreds of such cases showed that the extent of yellowing and firing of the leaves was roughly proportional to the length of the roots.

Another indication that drought was not entirely responsible was the noticeably moist condition of the layers of the soil almost directly beneath the seed stalks. Actual measurements prior to the first rain, on May 9, in one of the worst burned fields in Terrebonne Parish, showed an available moisture content of 8 to 16 per cent, based on the air-dry weight of the soil taken from the first 6 inches below the seed. There was therefore sufficient moisture to support a fairly heavy growth of cane had the roots been able to reach it.

Still another proof was the general behavior of more vigorous varieties of cane growing under identical soil conditions, as just de-



FIG. 3.—D-74 fall-planted cane, photographed May 21, 1925, showing the typical unevenness of the stand and the rolling and burning of the leaves of many plants caused by a severe attack of root disease. Although 1.65 inches of rain had fallen 11 days previously, the plants appear to be dying from drought. The large robust individuals to the right of the hat and elsewhere which have partially evaded the disease indicate, however, that root deficiency may be largely responsible for the unfavorable appearance of this field

scribed. Comparing only those varieties which were in the same stage of growth as the D-74 and the native canes, it was observed that Cayana-10, several of the United States seedlings, and two or three of the P. O. J. varieties, especially Nos. 228 and 2714, showed no marked yellowing or burning at any time during the spring drought. Their roots, however, were severely injured, though they succeeded in making more longitudinal growth and apparently suffered less rotting. The seed also remained sound for a longer period than that of D-74 or the native canes. These advantages, combined with their naturally more vigorous root growth, enabled these varieties to get at least a few roots well established in deeper soil before the surface layers dried out. Although they showed

no drought symptoms, the top growth was slow and suckering was retarded for nearly a month, compared with similar plantings on light soil.

EFFECT ON STUBBLE CANE

Root disease is usually more serious on stubble than on plant cane, because the conditions permit the undisturbed increase of the root-eating and root-rotting organisms. Its cumulative effect (of late accentuated by mosaic and other factors) reduces the number of profitable ratoon crops which might otherwise be obtained from an original planting. It has been many years since more than one or two successive stubble crops were produced in Louisiana on even the lightest soils. Cane cultivation is no longer attempted on large areas of the heavy soils. Thousands of acres of first-year stubble fields on such soils were plowed up or interplanted with other crops in the spring of 1924.

Unfortunately, there are no statistics extending over a period of years which show the separate yields of plant and stubble cane, nor are there any figures classified according to type of soil. That there has probably been a more or less gradual reduction in stubble yields, at least on the less favorable soils, is the opinion of many experienced planters. However, this reduction is evidently not of such magnitude or consistency as to affect greatly the combined yields per acre of both plant and stubble cane given for the State as a whole in Federal crop reports during the last 14 years. On the other hand, these final averages do not include the yields of the relatively large acreage of stubble cane ordinarily used for seed nor that for the sometimes large number of poor stubble fields plowed up or abandoned in the spring.

The Federal statistics from year to year on the area cut for sugar reveal large fluctuations in the tonnage of cane per acre since 1911, when acreage yields were first reported. Such wide variations alone suggest the influence of disease, the usual effect of which is to accentuate the normal variations due to climate or other factors. The noticeably wider variations in the figures since 1919, when mosaic was becoming general, have been attributed by some entirely to this disease. The results of a mathematical analysis of the question may be of interest. The variability in tonnage yields per acre for the periods from 1911 to 1918 and 1919 to 1924, inclusive,⁴ is of the order of 18.7 ± 3.26 per cent and 27.7 ± 5.82 per cent, respectively. The difference, 9.1 ± 6.68 per cent, representing the increase in variability since 1919, is obviously only about 1.4 times its probable error. With respect to possible differences in yields between the two periods, it is found that the mean for 1911 to 1918 is 15.57 ± 0.74 tons, and for 1919 to 1924, 12.81 ± 1.07 tons per acre, a difference of 2.76 ± 1.31 tons in favor of the earlier years. However, the difference is only twice its probable error. Though the data make it probable that a new yield-decreasing factor has been operating since 1919, the probability of this is not large enough to approach certainty. The statistics are suggestive rather than conclusive. However, as already stated, they pertain only to the area cut for sugar and do not include the abandoned fields or many other almost equally poor ones harvested for seed.

⁴ See Table I.—Cane Yields in Louisiana, 1901–1924, compiled by Edgerton, C. W., and others. Op. cit. [See footnote 3, page 2.]

All indications point to root disease as a factor of long-standing importance in Louisiana. The recent epidemic of mosaic, although apparently not greatly influencing available statistics, has undoubtedly intensified an already serious condition. Naturally the combined and probably interacting effect of mosaic, root disease, and red rot is more injurious than that of the latter two only.

SYMPTOMS ON STUBBLE CANE

In the beginning stages of the stubble crop the symptoms of the root disease are similar to the conditions already described for plant cane. Later a number of characteristic aboveground symptoms develop, which also apply to severe mid-seasonal cases in plant cane. These are (1) a slowing down of growth, (2) absence of or lateness of suckering, (3) rolling up of leaves at midday during periods of drought, (4) yellowing of the leaves (accentuated in plants also affected with mosaic), (5) premature dying of the lower leaves, and (6) rarely in severe cases a form of top-rot resulting from the death of the terminal bud. Most of these symptoms are suggestive of drought and might easily be thought to be caused by lack of sufficient water. The stubble plants growing on mixed land near Houma, La., shown in Figure 4, photographed August 10, 1924, illustrate this symptom, as well as many of the others listed. This field was typical of thousands of acres of first stubbles last year. Although a heavy rain had fallen but a few days previously, the leaves at midday showed much curling from lack of water.

When a diseased plant is carefully dug up and the soil removed, the roots will be found to be poorly developed, abnormally short and fibrous, and a large proportion of them black and dead. The root-stock may show decayed areas and sometimes in advanced cases envelopment of white mold (*Marasmius* sp. or *Sclerotium* sp.). Death of the older roots will have forced the plant to throw out new roots nearer the surface. In periods of even slight drought, such roots have difficulty in obtaining enough water to supply the plant and at best are scarcely ever able to support more than the mother stalk and a few weak suckers.

CAUSES OF ROOT DISEASE

ROOT-EATING ANIMALS

The type of root disease described in this circular, which operates most seriously during the early stages of the crop, is apparently a direct or indirect result of mutilation of the roots caused by at least three soil-inhabiting animals. One, and probably the most important of these, is a small, flat snail, *Zonitoides arboreus* Say, which is native in the United States and certain of the West Indies. The other two are centipedes. One is a long, threadlike, yellow species, identified as *Arenophilus bipuncticeps* Wood by R. V. Chamberlain, of the Museum of Comparative Zoology, Cambridge, Mass., who states (in correspondence) that it is a native form, common particularly in the Southeastern States. The other is a minute white 24-legged creature belonging to the order Symphyla. H. E. Ewing, specialist on this group at the United States National Museum, has identified it as *Hanseniella unguiculata* (Hansen) Bagnall, a species described from Venezuela and apparently not previously known to

occur in the United States. It is the second symphylid to be incriminated as a crop pest, the other being the common *Scutigerella immaculata*, recently reported to cause serious damage to truck crops in California and Oregon. Although other representatives of this order of animals have been collected in various sugarcane countries, as Argentina, Java, India, Mauritius, and Mexico, by zoologists interested mainly in their classification, none to the writer's knowledge has been reported attacking plants. In fact until recently little attention has been paid to their food habits.

The two other animals were also apparently not previously known to feed on living plants. That all three destroy cane roots has been repeatedly confirmed both by direct field observations and by feeding tests under confinement in the laboratory. They occur very abundantly in all of the cane soils, particularly in the so-called mixed and heavier types. They carry on practically their entire life in the



FIG. 4.—Disastrous condition of first-year stubble of the D-74 variety of sugarcane caused largely by root disease. The interplanted cowpeas were sown in July at the "lay-by" cultivation to keep down grass and weeds. Photographed August 10, 1924

crevices, earthworm holes, and the myriad other passages in the ground. When a cane root crosses or follows one of these innumerable crevices or channels, which it is often forced to do because of poor pulverization in the case of plant cane or the compacted condition in the stubble row, the animals attack it. They feed on the roots during practically 12 months of the year, from the moment the seed stalks take root in the fall until the last stubble crop is harvested. Rarely does a plant escape some injury. In some fields it has been impossible to find a root which was not more or less pitted or misformed. The extent and consequences of the injury, however, depend upon a number of interacting influences, such as soundness and vigor of seed, the fertility, moisture content, and physical condition of the soil, and the presence of root-rotting microorganisms, the relative importance of which is yet to be determined.

The damage is, of course, most serious in the spring, when the young plants are putting out their first shoots and becoming estab-

lished and independent of the mother seed stalks or of the old stubble rhizome. During this crucial period many plants are either killed outright or so retarded in growth that suckering is much delayed.

The chief effect of the root injury, as already indicated, is to hinder elongation of the roots by killing or weakening the soft white growing tips. If the roots have already attained some length before the tips are killed, laterals will develop and take their place. If the tips of these are also killed, they in turn branch; and so the plant goes on trying, as it were, to become established. This delay in the lengthening and expanding of the root system not only retards the growth of the plant through restriction of the absorbing area (important because of the short growing season), but, more especially, its very life is endangered through the possible occurrence of dry weather.

The appearance of the roots attacked by the snails was described by the writer in the *Journal of Agricultural Research* for November, 1924. The damage caused by the centipedes is very similar and has not been positively differentiated in many cases. Both types of animals produce a pitting of the root cortex, which may vary considerably in appearance, depending upon the area and portion of the root exposed. Often the entire root tip is honeycombed by large ragged-edged cavities or is wholly eaten away. On the older portions the pits or cavities are much smaller, circular, or lenticular in form, one-thirty-second to one-sixteenth inch in diameter, and extend inward only to the central root core. Often the white uninjured tissues surrounding the pits become discolored; as shown later, much of the root-rot plainly begins at such wounds. Figure 5 illustrates typical pitting and subsequent decay on young portions of roots, characteristic of initial stages of root disease.

The predisposing effect for root rot and other disturbances in growth resulting from mutilation of the roots by animal life in the soil has been observed by investigators in several other countries. Tschirch⁵ in 1891 considered the disastrous *seréh* disease of Java as primarily due to the destruction of the root tips by some soil-inhabiting animal. However, typical *seréh* was soon differentiated from what is now known as root rot in that country and, curiously enough, the most extensive investigations of the latter disease, made by Kamerling,⁶ indicated that a similar root mutilation was probably the initial cause. Although in several of his publications between 1900 and 1904, Kamerling refers to the typical holes and other malformations as appearing to have been "eaten" in the roots, his final conclusion was that such abnormalities were due to mechanical resistance of the soil particles. His hypothesis has apparently never been accepted, and to the writer's knowledge no further investigation has been made to determine the cause of the root injuries which he described.

In Hawaii the possible relation of animal organisms to root rot, or "*Lahaina disease*," was suggested by Kunkel in 1922.⁷ Preliminary investigations by Swezey and Pemberton disclosed extensive root damage by soil-inhabiting animals not only in many "root-rot fields" but also in others where the cane was in a more thrifty con-

⁵ Tschirch, A. Ueber *seréh*, die wichtigste aller krankheiten des zuckerrohrs in Java. In Schweiz. Wochenschr. Chemie u. Pharm., jahrg. 29, p. 47-52, illus. 1891.

⁶ Kamerling, Z. Verslag van het wortelrot-onderzoek. 209 p., illus. Soerabaja. 1903.

⁷ Agee, H. P. Director's report. Proc. Hawaiian Sugar Planters' Assoc., 42d Meeting, 1922.

dition. They found that the cane roots were gnawed to some extent by three kinds of snails, several kinds of sow bugs, a species of mite, and the threadlike centipede (*Mecistocephalus maxillaris*). The latter animal has lately been reported on in detail by Pemberton.⁸ It is somewhat similar in appearance to the longer of the two previously mentioned species of centipedes found attacking cane in Louisiana.

Although at first the Hawaiian workers were inclined to attach great importance to such animal injury as a factor in the local root-rot problem, they now apparently consider it only of minor primary significance. According to recent papers by McGeorge, attention is being directed toward chemical influences of the soil, especially the possible toxic effect on the cane roots of acid salts of iron, aluminum, and manganese. The chemical phase of the problem should also be investigated in Louisiana. However, as pointed out by various investigators, similarity of symptoms of the trouble in different countries or in different regions of the same country does not necessarily imply the same cause or causes. Nevertheless, the condition of occasional backward fields in Louisiana suggests the operation of some deleterious chemical or microbiological factor. Judging a priori from the known effects of repeated cropping of the same land in the case of other plants of the grass family—the cereals—the discovery of similar phenomena in sugar cane would not be surprising. It would supply an additional reason for the apparently increasing uncertainty of success in the cultivation of the old-established varieties.

If it is true that the root disease has steadily increased in importance in Louisiana, as the history of the industry indicates, it is probably due to the gradual development of a combination of factors unfavorable to the plant and operating to the advantage of the pests. The mechanical condition of the soil in old cane lands is now doubtless more favorable for their multiplication than in the earlier years of the industry. In preparing the seed bed, the heavy soils are more difficult to pulverize, leaving large crevices between the clumps, and when once settled the honeycombed structure resulting from burrowing earthworms remains nearly intact, so that the soil-inhabiting pests have abundant access to the roots. This is probably due partly to deflocculation of the fine soil particles in the absence of lime and also to the lack of enough vegetable detritus to keep the soil friable.

There is no question that the heavier soils have steadily deteriorated in physical condition as the original supply of coarse vegetable matter characteristic of virgin lands has disappeared. The occasional plowing under of quickly rotting leguminous crops, although of great temporary benefit, has apparently not maintained this desirable physical state. The soils are generally so compacted under the stubble crops that, apart from disease and possible differences in fertility and other factors, the roots of the common varieties of cane apparently have much difficulty in penetrating them.

During recent years the vigor of the cane has probably been greatly reduced by mosaic; this has doubtless increased the damage from root troubles, because any condition, constitutional or environ-

⁸ Pemberton, C. E. Cane-root injury by the centipede *Mecistocephalus maxillaris*. In Hawaiian Planters' Rec., vol. 29, p. 2-7, illus. 1925.

mental, which causes slower root growth allows the animals more time in which to destroy the root tips and thus prevents or retards the establishment and normal development of the plants.

Another aspect of the subject of the increasing importance of root disease is concerned with the possible significance of the general adoption of artificial chemical fertilizers in place of crude tankage and other organic manures formerly put into the ground with the seed. The prolonged stimulating effect on the plant of the latter materials is no longer present. They may possibly in addition have a biological significance. Decaying tankage, cane trash, and humus materials support rich mold growth in the soil. The small snail which feeds on the cane roots apparently also likes certain molds. Whether or not cane roots are its preferred food, it can readily exist without them; in fact, it lives in its supposedly native habitat in old rotting logs. The gradual decrease of mold growths in the soil on account of diminished plant refuse following the burning of trash, insufficient green manuring, and the abandoning of crude organic fertilizers has possibly turned these little animals more and more to the cane roots as a source of food.

ROOT ROT

Root rot in a great many cases is directly traceable to wound infection by a number of soil-inhabiting microorganisms. Incipient decay often appears within a few days after the snails or centipedes have fed on the roots. Sometimes, however, the frayed edges of the pits, or cavities, merely shrink and apparently never become infected. Where subsequent rotting occurs it may, under certain conditions, suppress and destroy more roots than are directly affected by the animals themselves. It is more common under very moist than under dry conditions. Thus, during the dry weather last spring very little rotting was evident on the severely injured roots of fall-planted cane. However, after the first heavy rains in May it became very common and apparently did considerable damage to the already deficient and weakened root systems, resulting in further retardation in growth and delay in suckering.

The decay of the roots is usually manifested by reddish, brownish, or black-colored areas (see fig. 5). These should not be confused with the natural darkening and shrinkage of dying root cortex on old roots, which are normal processes in the development and maturity of all healthy cane roots. The latter begin a few inches back of the white terminal portion of the root, after the central active bundle of food and water conducting strands has become well protected by the deposition on its surface of a hard, waterproof layer or sheath. This wiry armored core of all mature roots is thus naturally fairly well protected against the parasites. It is therefore toward and on the soft elongating undifferentiated terminal portion that animal injury and subsequent discoloration and rotting are particularly serious.

It has already been stated that discoloration and decay commonly follow snail and centipede injury to the roots. Isolation and pure-culture study in such cases reveal the presence of a number of soil-infesting fungi. These are species of *Fusarium*, *Rhizoctonia*, *Marasmius*, *Sclerotium*, *Colletotrichum*, *Penicillium*, *Mucor*, and other molds. Bacteria also are frequently present.

Observations during the seasons of 1924 and 1925 indicate that a large proportion of the root decay was probably a secondary phenomenon to snail and centipede injury, but there is no definite proof that all cases of root rot start from such wounds; in fact, decayed roots and lesions on otherwise apparently healthy roots have been found

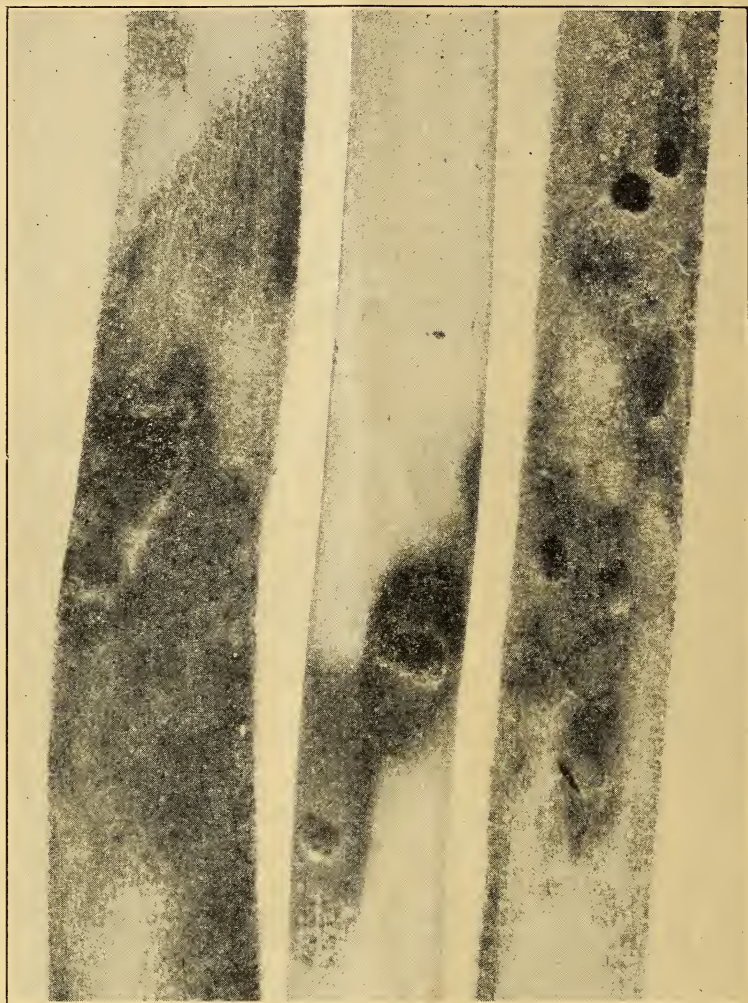


FIG. 5.—Typical pitting of young sugar cane roots caused by snails and centipedes and the subsequent decay characteristic of initial stages of root disease. Enlarged seven times. (Photographed by J. F. Brewer)

on which no snail or centipede pitting could be seen. However, these observations do not necessarily admit the conclusion that no wounds were present. They may have been very small, and the shrinkage of the decaying tissues may have merely obliterated their identification. A study of the feeding habits of young snails in confinement shows that they often make only microscopic wounds. In passing along a

root, they have been observed to eat at the root hairs and take a few nibbles at the root cortex in several places before finally selecting a spot to drill a hole. All signs of such small injuries, which in the fresh condition are scarcely discernible with a high-power magnifying glass, quickly disappear upon becoming infected. Therefore it is possible, although not proved, that most of the root rot in Louisiana starts by infection through injuries caused by snails, centipedes, or other soil-inhabiting animals.

Enough has been said to indicate the complexity of the problem of determining the relative importance of primary and secondary agents in cane-root deterioration. Much more time and controlled painstaking experimental work will be necessary to probe its various ramifications. Possibly it may then be shown that root rot, independent of animal injury or other predisposing conditions, is more important as a primary factor than now appears to the writer from purely observational evidence.

Edgerton, Taggart, and Tims,⁹ in a recent discussion of the problem in Louisiana, emphasize the importance of root-rotting fungi, which they apparently consider the major factor in root deterioration. Infection experiments carried out by them with fungi isolated from diseased plants, made on roots grown in glass tubes in the laboratory or in sterile soil, reproduced lesions similar to those found on plants in the field. Although of great interest, it is questionable, considering the obviously abnormal conditions under which the inoculated roots were grown, whether the same fungi necessarily would attack sound roots in nature. These writers admit, however, that the organisms isolated by them are weak parasites, and they stress predisposing factors, such as unfavorable environment and root-eating animals.

A number of tests are now under way in which it is hoped to isolate and determine separately under natural and varying field conditions the relative influence of the root-mutilating and root-rotting phases of the disease. Thus, in some experiments the animals have been killed by fumigating the soil along the cane row, and the effect of the rotting organisms in the absence of animal injury has been studied. No conclusive evidence is yet available, but soil fumigation has demonstrated a pronounced preventive effect on the occurrence of the disease, that is, on both injury and rotting.

One experiment with spring-planted cane may be cited. The common soil fumigant paradichlorobenzene was used. It was observed that, where this substance was applied to the sprouting cane (the D-74 variety from windrowed stubble) at a rate strong enough to kill the animals but without chemical injury to the roots, root rotting was rare. This was true in all cases for this particular treatment (one-half ounce per linear yard), which was replicated six times in short rows well distributed over an acre block of heavy black soil known to have produced a severely diseased crop of stubble cane last year. The checks, or untreated rows, on the other hand, were usually severely affected. These were always directly adjacent to the treated rows and were similarly distributed and replicated to counterbalance variations in soil moisture, rate and depth of planting, etc. The roots in these control rows showed extensive reddish brown or black areas and were often entirely rotted. They had also

⁹ See footnote 3, page 2.

been much pitted and stunted by the soil animals. The difference in appearance between the treated and untreated plants was therefore very striking; the long, clean, white roots of the fumigated rows, never having been observed before on such soils in Louisiana, reminded one of greenhouse-grown cane.

If the rotting organisms present in this Louisiana field were not dependent upon animal injuries for entrance into the root tissues, one would expect similar decay of the roots in the fumigated rows, unless the fumigant had also a deleterious effect on this form of life. That at least some of these vegetable organisms were not affected was indicated by the fact that species of *Marasmius*, *Sclerotium*, and *Fusarium* were found growing luxuriantly in one row on dead leaf sheaths and other cane detritus clinging to or near the sprouting seed in soil which had a pronounced odor of the fumigant.

The difference between the treated and the untreated rows was further illustrated by the relative stands obtained. Thirty-seven days after planting, there were six times as many plants in the fumigated rows as in the controls, which ratio, however, after two months with intervening rains, was reduced to 3.5 to 1 on account of further germinations in the controls.

The conditions surrounding this experiment were very abnormal, because of the poor physical condition of the seed bed, poor quality of seed, lateness of planting, and the entire absence of rain for 39 days after the cane was planted. The seed, however, was put in deep where there was generally enough moisture for germination, but the chemical placed 2 inches above in loose dry dirt was entirely dissipated in less than a month, allowing reoccupation of the fumigated strip by the root-eating animals. Root injury and rotting then became prevalent in the treated rows; and the earlier vigor of these plants, compared with the controls and adjacent fall-planted cane, largely disappeared. Thus, the only noticeable difference after three months was that of stand. This experiment and others even less decisive are not comparable with what might occur during a normal spring, but the results are sufficiently indicative to warrant more extensive tests, which are now being carried out.

RECOMMENDATIONS

ADOPTION OF TOLERANT VARIETIES

One recommendation can be definitely made, and that is to adopt more vigorous disease-resisting varieties of cane.

D-74 and the so-called native canes have been satisfactory in the past and still give fair yields; but this is true only under the most nearly ideal weather conditions for cane growth. Because of their susceptibility to diseases and their comparatively weak root systems with low recuperative and foraging ability, they are apparently no longer able to withstand the changed conditions of soil and the variations of climate to which they are of necessity exposed.

The Java seedling, P. O. J. 234, distributed by the United States Department of Agriculture and the American Sugar Cane League in the fall of 1924, although sometimes severely attacked by the root-eating animals, generally puts forth new roots fast enough to withstand its injuries, largely because of its great natural vigor

(inherited from its slender, more grasslike ancestor Chunnee). It is by no means an ideal cane, but its earliness, heavy stooling, and ratooning qualities appear to be sufficiently superior to the common varieties, even on the heavier soils, to commend it to the earnest attention of every sugar-cane grower.

Commercial plantings of this variety by the managers of the Southdown plantation have demonstrated, among other things, that only three-fourths to 1 ton of seed per acre need be planted to obtain a stand on light soil. However, on heavy soils this quantity should be increased by at least a half ton, to offset losses from disease through possible unfavorable seasonal conditions. Contrasted with the old varieties, this represents an estimated saving of at least \$15 per acre. The fields shown in Figure 6, photographed November 7, 1924, illustrate even better this difference between the old and the



FIG. 6.—Relative quantities of seed required to obtain a stand of sugar cane, D-74 (above) and P. O. J. (below), Southdown Plantation, Houma, La. Photographed November 7, 1924

new. Therefore, it is evident that a much higher proportion of the sound eyes of this P. O. J. 234 cane succeed in producing plants, due probably to its greater resistance to red rot, root disease, mosaic, and other deteriorating influences. For these reasons it is admissible to cut the seed into 16 to 18 inch lengths, which also guarantees more uniform germination through elimination of the temporary growth suppression of the eyes in the middle of the stalk operating in case of full-stalk plantings.

Since, among several superior types, P. O. J. 234 is the only one of which a large seed stock will soon be available, its general adop-

tion by the industry, pending the distribution of still better varieties, is recommended. Several apparently more promising canes, such as P. O. J. 36, 213, 228, 979, and 2714 and 36M, are now being tested and increased as rapidly as possible by Federal, State, and private agencies. Comparisons of duplicate plantings of these varieties, along with a large series of selected United States seedlings on typical light and heavy lands at the Houma field station, illustrate the necessity of developing varieties adapted to the various soil types. On account of the almost invariable occurrence of root disease in the heavy black lands, only those types possessing exceptional vigor and tolerance of mosaic may be expected to yield a series of profitable ratoon crops. Observations during the present season indicate the superiority in these respects of varieties of the Chinese type, such as Kavangire, Merthi, and Cayana-10, and particularly seedlings of Kassoer parentage. Even the massive P. O. J. 2714, which contains only one-quarter Kassoer blood, showed in 1925, in spite of the unfavorable spring, remarkable development in the heavy soil of the experimental plats.

DIRECT CONTROL OF ROOT PARASITES

Extensive experiments are now being carried on with the object of discovering and perfecting a practical method for control of the root-destroying snails and centipedes. Since even the most vigorous mosaic-immune varieties are sometimes seriously retarded in growth and reduced in stand before the plants become established, the importance of such investigations is realized. If the damage, which the writer's observations indicate is caused by these soil-inhabiting pests, can be prevented, not only greatly increased yields of more mature plant cane, but an increase in the number and productiveness of stubble crops should be obtained. The experiments involve tests of several possible methods of control, such as soil fumigation, the application of animal deterrents, poison baits, and special soil treatments. A preliminary experiment indicating promising possibilities from soil fumigation with paradichlorobenzene has already been described.

Inundation for several days of parts of fields in irrigation operations last summer apparently greatly reduced the number of both snails and centipedes. Several river farmers, who have for years alternated cane with flooded rice crops, maintain that their yields of cane are thereby greatly increased. However, examinations made in plant cane the second year after the land had been flooded, i. e., after an intervening crop of corn and cowpeas, showed that the pests had either not been completely eradicated or had been reintroduced; and in the succeeding stubble crop, root injury was nearly as bad as in adjacent fields under the ordinary rotation. These scattered observations are mentioned merely to encourage growers to be on the lookout for significant differences in the amount of root disease which may appear in their fields as a result of variations in cultivation or rotation practices.

SOIL IMPROVEMENT AND BETTER METHODS OF CULTIVATION

The extent and permanence of the prosperity which the substitution of more hardy varieties may bring will depend largely upon the handling of the fundamental soil problems which now exist in the

older established sugar-cane areas of Louisiana. Root disease and humus-deficient and compacted soils are major problems in nearly every sugar-cane country in the world. The plant breeder can not be expected to overcome all the defects of past agricultural practices. The large-barrel, high-sugar-yielding, long-ratooning variety so much desired by all must, of course, have a suitable soil in which to grow. The experience of several planters shows that the unfavorable physical condition of the heavy soils can be greatly improved by regularly turning under all of the cane trash. This practice can not be urged too strongly for all types of sugar-cane soils.

Soil conditions in Louisiana have apparently so changed since the early researches of Doctor Stubbs and his colleagues that reexamination of at least some of the plantation methods in the light of a better understanding of root troubles is urgently needed. For this purpose and to supplement and correlate important work by the State agricultural experiment stations and Federal stations in Georgia and Florida, some of the fields of the newly established Government station on the Southdown plantation, near Houma, La., will be utilized.

SUMMARY

In this circular an attempt has been made to outline more clearly the symptoms and effects of the sugar-cane root disease in Louisiana and to call attention to its damage, especially during the early stages of the crop. Evidence is presented which shows that on the heavier soils, at least, root disease is largely responsible for the seriously reduced yields.

The results of further studies to determine the cause or causes of the trouble confirm the writer's earlier conclusion that root mutilation by soil-inhabiting snails and other root-eating animals is of primary importance. The discovery in the United States of two species of centipedes very generally attacking the roots and causing part of the damage earlier attributed by the writer to snails, is reported.

Although much of the prevalent root rotting is undoubtedly initiated by animal injury to the roots, the complexity of the problem is such that further study and experimental work are necessary to determine more definitely the relationship of the various factors involved.

Soil fumigation with paradichlorobenzene has demonstrated in preliminary tests on spring-planted cane a decidedly preventive effect, at least temporarily, on both root mutilation and root rot.

Since pronounced differences have been noted between varieties in their reaction to the root disease (this term being used by the writer to include both root injury and subsequent root rot), the trouble may be largely controlled, at least on the lighter soils, by the substitution of more vigorous disease-evading or tolerant varieties. For this purpose several of the P. O. J. seedlings, which are also tolerant of mosaic, may be recommended because of their superiority to the common varieties.

The necessity of taking measures for the improvement of the physical condition of the heavier soils is emphasized, since no very desirable high-sugar-yielding variety is at hand that appears capable of eliminating the uncertainties of root disease on this type of land.

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January 30, 1926

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20

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